more grades of product may be shown by different shadings or the relative amount of healthy and diseased fruit or vegetable. Like all similar devices, they admit of errors of statement and need to be constructed with great care and then should always form an adjunct of the text.

The personal equation needs to be reduced to the lowest terms and the experimenter should test this at frequent intervals by calling to his aid the judgment of the disinterested person, who is competent to arbitrate. A person with his eye fixed upon some point to be reached may be oblivious to side lights that play an important part.

The born experimenter we may expect in the next generation, but the present station workers needed to be made and that quite quickly. When the ideal truth searcher comes we shall be shown how best to work for the truth, the whole truth, and nothing but the truth.

BYRON D. HALSTED.
COLLEGE EXPERIMENT STATION,
NEW BRUNSWICK, N. J.

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*MODERN PROBLEMS IN ACOUSTICS.**

THE subject of acoustics appeals in one or more of its phases to a wide range of people:

To the mathematician, for the laws of vibrating bodies furnish countless problems that tax his science to the uttermost;

To the physicist, to whom primarily the field belongs;

To the architect, whose business it is to design auditoriums fitted for hearers as well as for spectators;

To the anatomist and physiologist, who finds in the organ of hearing a wonderfully complex structure that is incomprehensible without the aid of acoustical principles;

To the psychologist, who investigates the operations of the mind concerned in the hearing of sound;

To the instrument-maker, who must furnish the musician the means of expression and help him develop them;

To the musician, who cares to know the historical development and the foundations of his present art;

To the ethnologist, who recognizes music as one of the most important expressions of the life of a people; and lastly,

To all intelligent men who find with the Roman 'nothing of human interest alien to them,' and realize that a subject of such world-wide, time-long, interest as music may be studied profitably even by those who are not numbered among musical performers. For they appreciate the fact that here, as everywhere, the ability to learn *why* the alien does what he does, to enter sympathetically into his thought and see through his eyes, is the subtle power which distinguishes culture from mere knowledge.

In accordance with the custom of these Reports we are to take a bird's-eye view of recent progress in the science of acoustics.

I. In the history of acoustics two names are pre-eminent: Chladni, the text-book writer, who united to wide knowledge of the subject great ingenuity and experimental skill; and Helmholtz in whom there was a unique combination of mathematician, physiologist, physical experimenter and musician. His *Sensations of Tone as a Physical Basis for Music* published (in German) in 1863, and his monographs summed up in it, contained enough in each of these four lines to make one famous. The book has for nearly forty years dominated the thoughts of most people who believe that the science of acoustics has anything to teach musicians. Still it is significant that musicians have largely refused to recognize its sway, some showing crass ignorance in their comments, others making it clear that there is something in

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the appeal of music to the human mind and heart that eluded his philosophy.

Though this ancient question of the physical basis of music is still a problem, there is time here to note but two points, and these have reference rather to the mode of attack than to the problem itself: (1) What scholarly musicians of to-day think of as music differs to an important extent from what was in Helmholtz's mind forty years ago as truly, though not as widely, as it differs from mediæval music; (2) Materials available in recent years for the historical study of European and Oriental scales disclose several consciously-used principles of scale-building which could not result in the diatonic or harmonic scales for which Helmholtz's overtone and resultant-tone theory furnished so strong a justification. Perhaps the greatest value of the book has been its stimulus to investigation in many fields, especially in the psychology of music; yet in spite of all our modern progress the greater part of the work remains as indispensable as ever.

II. Since the publication of Hemholtz's work the most noteworthy things in connection with Acoustics have been:

1. The multiplying and perfecting of methods and instruments, especially by König and Appunn; the development of the phonograph; the application of photography.

2. The publication of Rayleigh's mathematical *Theory of Sound;* of the ten volumes of the *Vierteljahrsschrift für Musikwissenschaft,* full of scholarly monographs on the musical and historical side; and of Ellis & Hopkins' researches on musical scales.

3. The developments in musical instruments (especially the piano), so giving us instruments of more accurate intonation and of greater power, and unfortunately driving out the older soft-toned instruments.

4. The general introduction into the household of the piano or reed organ, often leading psychologically to the conviction that there can be no music without harmony.

5. The building-up of several great collections of musical instruments from various lands and times, and the publication of books and monographs based thereon.

6. The accumulation of a vast amount of observations and experiments in the field of music-psychology.

III. Confining our attention now to Physical Acoustics, we may consider a little more in detail some of the recent advances that can readily be grouped together.

The *Velocity of Sound* in free air has been shown to increase greatly for very intense sounds, and has been measured in air compressed up to 100 atmospheres; the velocity in air confined in tubes is found to be a function of the diameter and nature of the walls, and of the pitch. The velocity in solids has been much studied, and measured even in such soft bodies as paraffin and rubber.

The *Frequency of Vibration* in specially favorable cases is now measured to within a few parts in a million; so the writing tuning-fork is now the usual means of dividing a second, say into 100 parts; but in ordinary cases, especially where the pitch is high, or the sound weak or of short duration, errors of some per cent. are frequent. Quite recently the sets of high forks made by Appunn for physiologists have been found to be extravagantly in error; but as partial compensation for the disappointment the science has been enriched by new experimental methods.

Of extreme importance to the modern physicist is the question of the energy involved in any movement. The experimental study of *Intensity of Vibration* began, I believe, with Töpler and Boltzman's ingenious optical determination, in 1870, of the actual variations in density in the air of a sounding organ pipe, and the distance

at which it could be heard, and so the energy per second required at the limit of hearing. More recently a Swedish experimenter found, by periodically thrusting a thermopile, mounted on a tuning-fork prong, into a sounding pipe at the node, a rise of 0.1° C., due to the adiabatic compression. Since 1870 experiments on the energy of organ pipes, etc., have been multiplied and refined. Similarly, determinations on the intensity of telephone currents and the movement of its disc have testified to the incredible sensitiveness of the ear. An amplitude of vibration of air particles of only one fifteen millionth of a millimeter in the region of 440 d. v. produces sensation.

Other investigations have traced the expenditure of the energy once stored in a vibrating mass; so the rate of damping of forks under various conditions has been observed; also the dissipation of energy in a resonator and the decay of sound in free air: it has been noted that a sound reflected repeatedly through a tunnel changes in quality, owing to the more rapid absorption of the overtones of high pitch. A contrary analytical effect is observed in some cases of echoes, as from a forest, where the sound of the voice seemed to come back raised an octave.

The relative absorbing power of various fabrics has lately been measured by Sabine. From his data I calculate that for a note of 256 dv. 0.33 of the energy falling on a sheet of hair felt one-half inch thick is absorbed.

A few instruments have been devised to produce a tone of definite reproducible intensity, and other instruments to indicate or measure the intensity of vibration at a given point. In Wien's beautiful manometer the minute yielding of a part of the wall of a resonator is measured by mirror and scale to one five hundredth part of its maximum amount, while the absolute value of the scale readings is determined to within a few per cent.

The study of *Form of Vibration* or *Quality of Sound* has been prosecuted both synthetically and analytically. König many years ago challenged Helmholtz's conclusion that the quality of sound depended only on the strength of the overtones, not on their relative phase; and he invented his wave-siren to prove his position. In this instrument the flow of air through several slits is carved into waves by several rotating discs, whose edges are cut into harmonic curves. More recently he has greatly perfected it, and attempted to meet various criticisms made against his earlier work; but so many lines of argument support Helmholtz's view, that I do not think this brilliant attack will generally be admitted to have conquered the field. A more reliable means of synthesis than the wave-discs is found in Appunn's sets of organ pipes; these furnish a great number of harmonics of one fundamental, and for each harmonic there are two pipes, a weak-toned and a strong-toned one.

Analytically the problem of form of vibration has been attacked in various ways, especially by photography. If the vibration to be examined is in the air either the König's flames connected to a set of resonators may be photographed, or a little mirror on a convenient speaking tube may throw a spot of light on the sensitive plate. If the sounding body is a wire, it is mounted to vibrate before a transverse slit through which light falls on the sensitive surface moving parallel to the string. Compound curves produced in either way are then subjected to harmonic analysis. In passing it may be noted that Mach obtained a photograph of a sound wave in air as far back as 1888.

The superposition of two vibrations has been further studied with reference to the pitch actually observed when two notes are beating; the old theory of combination tones has been rudely shaken and their objective existence proved experimentally in

certain rare cases. Mechanical superposition of harmonic motions has been obtained by many elaborate forms of harmonographs or curve tracers.

Both physicists and physiologists have devoted much attention to the study of the complex curves due to vowels and speech-sounds, working especially by aid of the phonograph.

Two or three matters of industrial as well as of scientific importance may also be noted, viz, the enormous development of speaking instruments—phonograph, graphophone, gramophone; the adoption by the Piano Makers' Association of the U. S. of the French standard tuning-fork giving A = 435 d. v.; and many improvements in organ pipes and reed stops that show a practical control over the wind sheet such as the older builders had not obtained.

IV. And now what are some of the most important *problems remaining to be solved?*

1. In pure physics: The simplification of the means for the precise determination of pitch in the ordinary practical cases; the establishment of convenient standards of intensity, and the perfecting of experimental means of measuring intensities; the development of means for the thorough analysis of sounds.

2. In connection with instruments: The thorough study of the action of the sounding board of a piano; of reeds as actually used in common instruments, and of the laws of the perforated tube as applied in flutes, etc.; the determination of the quality of tone produced by our common instruments under the conditions occurring in practice. Some day it will be possible to make as thorough and scientific an examination of a musical instrument as it now is of a steam plant or a dynamo. On all the points just noted current statements are inadequate, for the art is now so developed that the knowledge of the laws of vibrating bodies to the first approximation only is insufficient for future guidance.

3. In connection with architecture: the determination of the reflection or absorption coefficient of the various materials used in building for inside walls, with the numerical evaluation of the several factors that influence the acoustic properties of an auditorium; and the acoustic survey of auditoriums, showing the intensity of sound at all points where hearers might be placed.

4. In connection with practical life, the physicist finds the important problem of fog signals still unsolved.

5. On the side of psychology and music there may be named the further study of the capabilities and deficiencies of the human ear; the influence of instruments on musical conceptions; the historical, psychological and practical nature of the scales in use among various peoples; these branches bring our material study into intimate relations with human development.

V. In view of the manifold interests that center in the subject of acoustics, scientific and commercial, æsthetic and utilitarian, specific and general, it seems strange that neither by endowment in connection with a University, nor by government appropriation has provision been made for a well-equipped acoustical laboratory; for here the same reasons apply that justify similar expenditures for so many other branches of science, viz, that the subject is of large importance, either industrially or in its relation to past and present human activities; that the results of investigation would be of value to the community at large, being far wider than could be monopolized by the investigators; that the necessary expenses are beyond the means of the individual experimenter; and that nowhere in this country or the world is there any systematic exploiting of this field.

CHARLES K. WEAD.